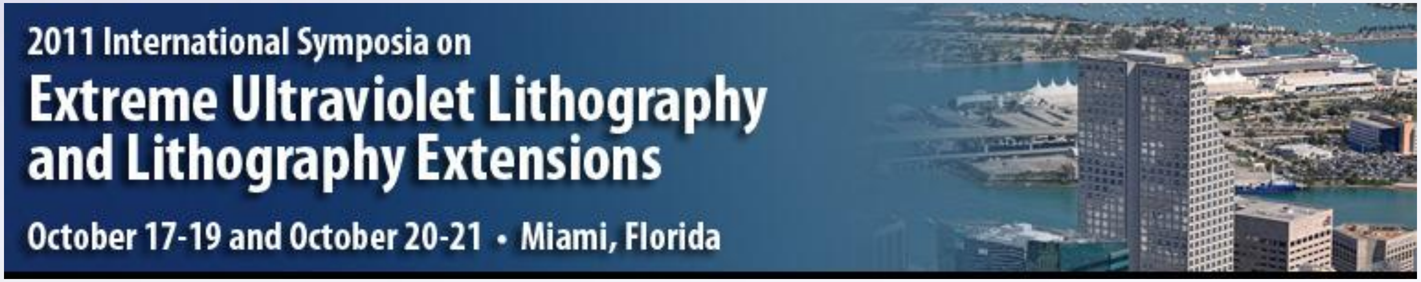

Requirements and Challenges of EUV mask inspection for 22nm HP and beyond

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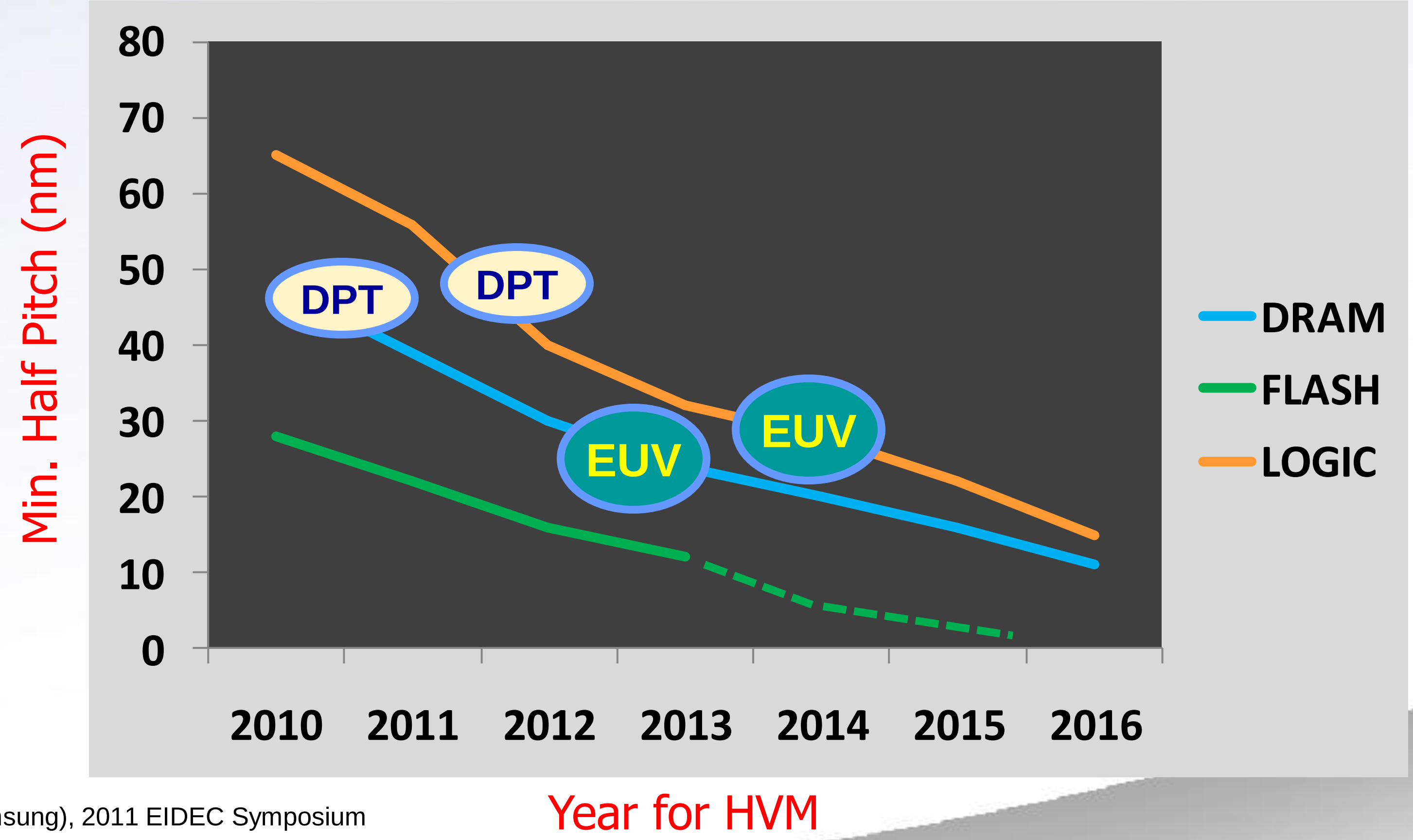
Outline

- Background
  - Device roadmap, EUV mask defect requirements
- EUV mask inspection challenges
- Requirements and current status of EUV mask inspection
  - Sensitivity
  - Inspectability
  - Throughput time
  - Other considerations (DB inspection, Defect review, Timing)
- Risk estimate of inspection tool
- Conclusions

Device roadmap

- 1st EUV HVM insertion is expected between 2013 and 2015
- DRAM device roadmap is at least 1 year ahead of Logic device roadmap



Han Ku Cho (Samsung), 2011 EIDEC Symposium

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EUV mask defect requirements

		2011	2012	2013	2014	2015	2016
Device node (DRAM, HVM)		D2X-a		D2X-b		D1X	
EUV scanner		1st Gen.				2nd Gen.	
BI (Blank Inspection)	Particle Spec (nm)	60 SiO2	23 SEVD	23	23	15	11
	19Xnm						
	13.5nm						
PI (Pattern Inspection)	Defect Spec (nm)	40 Experiment		30 Simulation & Estimation		20	<10
	19X nm						
	13.5 nm						
	E-beam						

- Blank particle spec. should meet ≤ 10 printable defects in each node
- Pattern defect spec. is based on printability

	Positive
	Need development
	Negative

Keywords for EUV mask inspection

- **Patterned Mask Inspection Considerations**
  - Detection Limit (Sensitivity, capture rate)
  - Inspectability (false rate, nuisance)
  - Optimization of blank stack with inspection conditions
  - Throughput time
  - Defect of interests
  - Focus control
  - Illumination optimization
  - Defect printability based on wafer printing
  - Tool Roadmap alignment with Device roadmap (timing)
  - Inspection light source (19Xnm, E-beam, 13.5nm)

- Blank Mask Inspection Considerations
  - Sensitivity
  - Position Accuracy
  - Inspection time
  - Inspection light source (19Xnm, 13.5nm)
  - Dark field/Bright field

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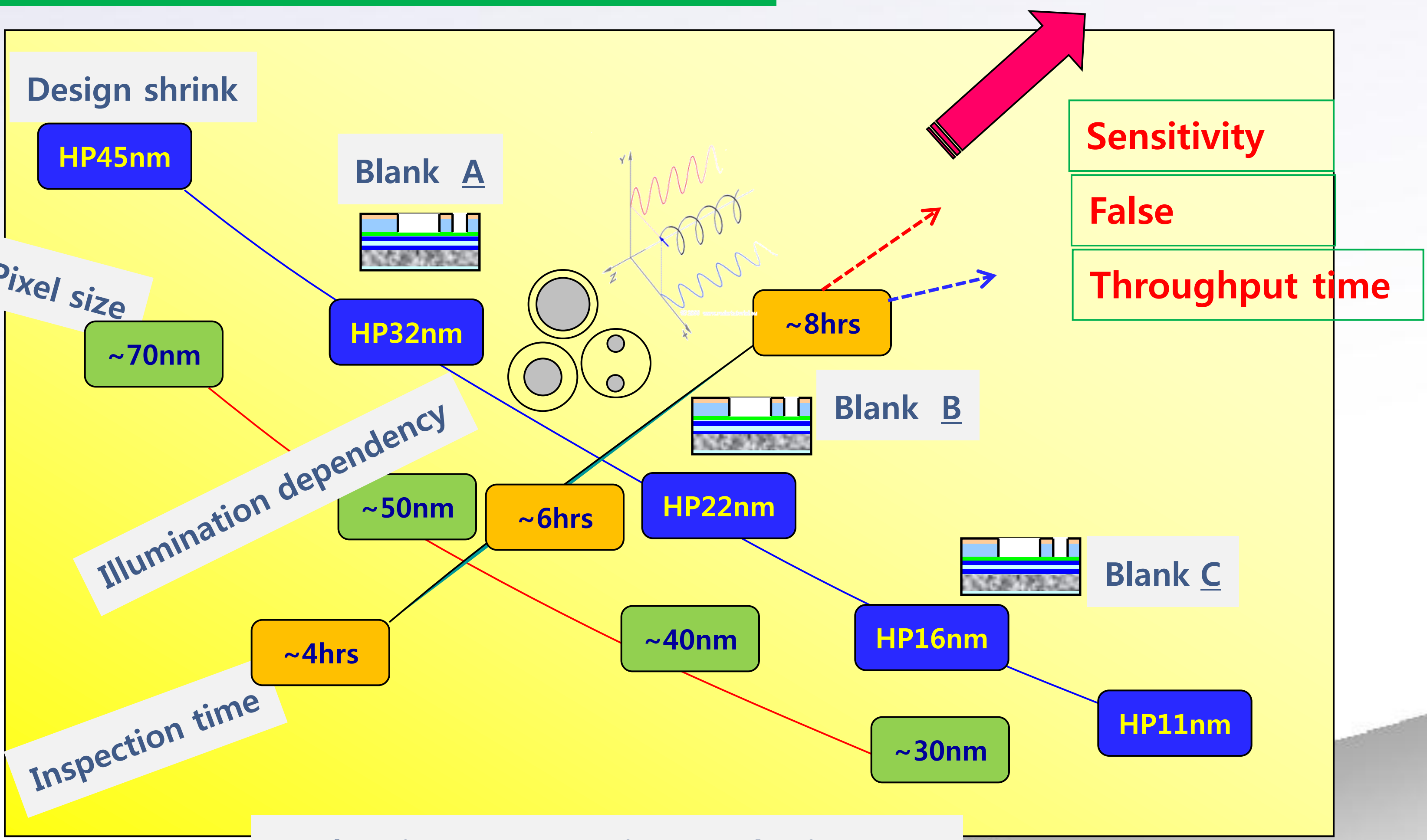
Inspection challenges !!

- Inspection environments are getting worse !!

CoO increase !!



Mask noise, System noise → False increase

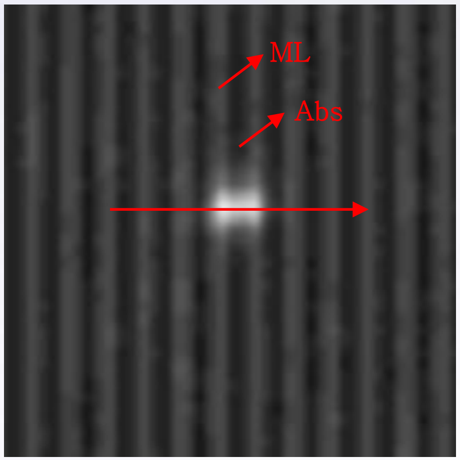
Sensitivity

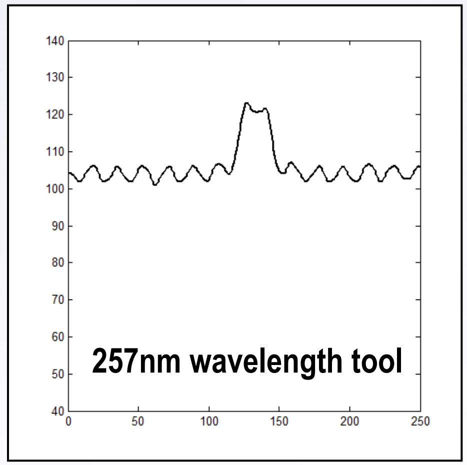
	Descriptions
Requirements	• 30nm HP → ~40nm (4X) , 22nm HP → ~30nm (4X) • 16nm/11nm HP → ??
Current Status	• 19X nm inspection light source shows reasonable capability at 30nm HP but still challenging at 22nm HP • Specific EUV blank stack is critical to secure 19X inspection capability. • Tone reverse with 19X nm causes issues • No available data beyond 16nm HP
Expected Risks	• Technology gap between 19X nm and Actinic is apparent • Timing gap is most critical before Actinic is used
Focus Area	• Extendibility of 19X nm inspector with various optical enhancement technology (OAI, High NA, polarization, etc) • Inspection simulation capability down to 16nm HP • EUV blank optimization • Review of the necessity of E-beam inspection

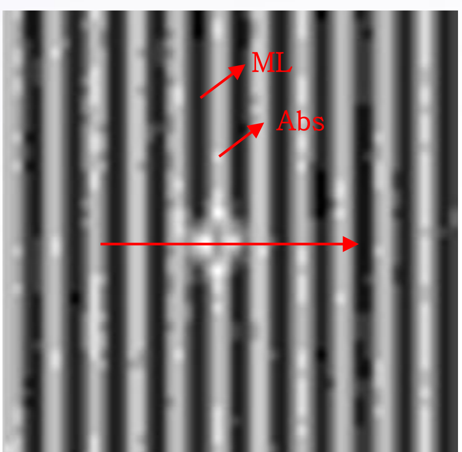
Imaging property depending on wavelengths

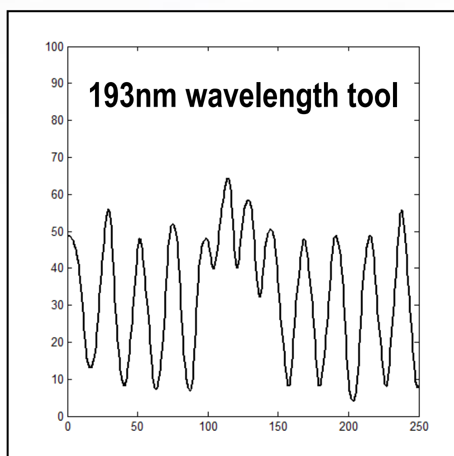
Inspection image

Each tool shows different result with a same defect.

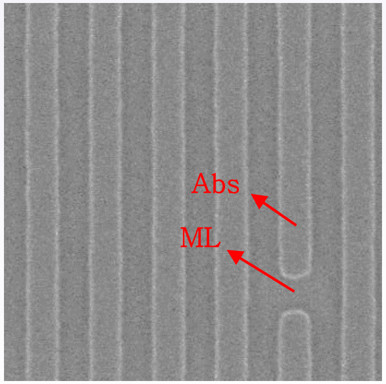








CD-SEM image

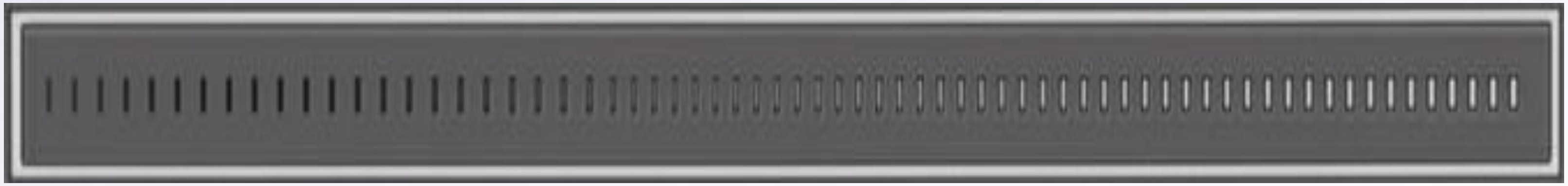


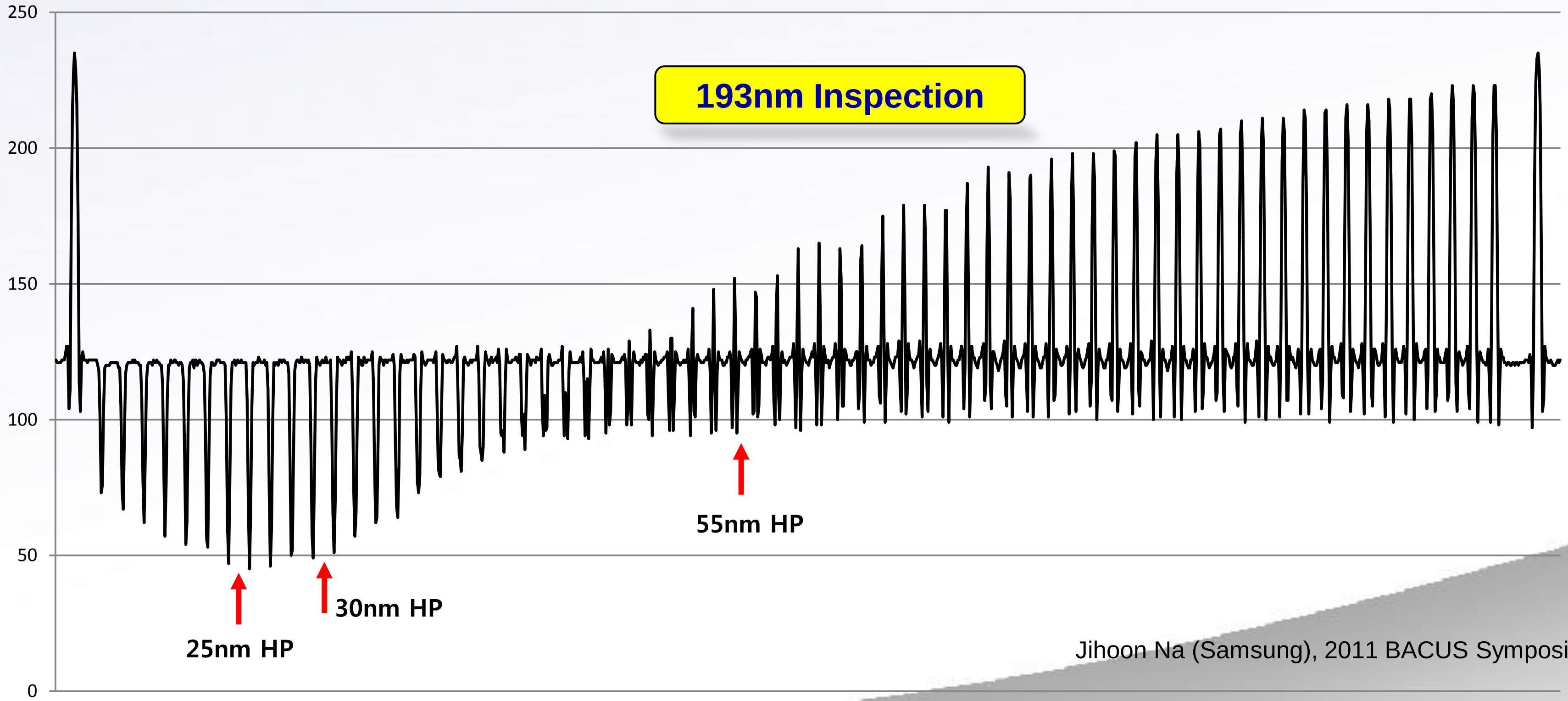
Cut defect case (intrusion)

Jihoon Na (Samsung), 2011 BACUS Symposium

Tone reversal

- Signal behavior with different pattern size (length 1 um, width 400nm ~70nm) – tone reversal is clearly seen.

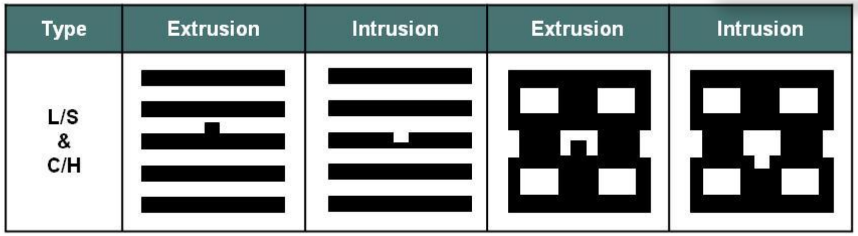


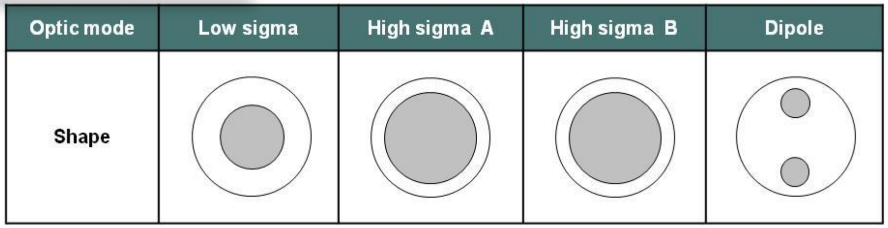


Jihoon Na (Samsung), 2011 BACUS Symposium

Detection sensitivity – L/S pattern

193nm Inspection





30nm HP L/S		1	2	3	4	5	6	7	8	9	10	11	12
Extrusion	Printability (Mea.)	BR	BR	BR	BR	BR	82.1nm	76.5nm	59.4nm	44.8nm	38.0nm	32.0nm	
	Low sigma	100%	100%	92%	100%	88%	100%	100%	100%	100%	100%	60%	
	High sigma A	100%	100%	88%	40%	0%	0%	4%	56%	80%	92%	28%	
	High sigma B	100%	100%	100%	100%	72%	20%	16%	52%	80%	64%		
	Dipole	100%	100%	100%	100%	100%	100%	100%	100%	100%	88%		
Intrusion	Printability	Cut	Cut	Cut	Cut	100.3nm	81.8nm	68.7nm	56.4nm	42.0nm	32.4nm		
	Low sigma	100%	100%	100%	100%	100%	100%	100%	100%	100%	72%	24%	
	High sigma A	100%	100%	100%	100%	100%	100%	96%	84%	60%	28%		
	High sigma B	100%	100%	100%	100%	100%	100%	100%	88%	64%			
	Dipole	100%	100%	100%	100%	100%	100%	100%	100%	96%	24%		

24nm HP L/S		1	2	3	4	5	6	7	8	9	10	11	12
Extrusion	Printability (Sim.)	BR	BR	BR	BR	65.3nm	54.1nm	49nm	39.8nm	32.2nm	29.2nm		
	Low sigma	100%	100%	100%	100%	100%	100%	100%	96%	84%			
	High sigma A	100%	100%	100%	100%	100%	100%	100%	100%	96%	24%		
	High sigma B	100%	100%	100%	100%	100%	100%	100%	40%				
	Dipole	64%	48%	36%	20%								
Intrusion	Printability (Sim.)	CUT	CUT	CUT	CUT	68.1nm	58.6nm	53.3nm	41.8nm	38.2nm	29.1nm		
	Low sigma	100%	100%	100%	100%	100%	100%	96%	52%				
	High sigma A	100%	100%	100%	100%	100%	100%	100%	84%				
	High sigma B	100%	88%	72%	92%	96%	56%						
	Dipole	100%	100%	100%	100%	100%	100%	100%	88%	28%			

Sensitivity dependency of illumination conditions

193nm Inspection

- 30m HP L/S

IC		Low sigma	High sigma A	High sigma B	Dipole
Modulation depth		Not bad	Bad	Good	Very good
Defect signal	Extrusion	Not bad	Not bad	Good	good
	Intrusion	Very good	Good	Good	Very good
Detection sensitivity	Extrusion	Very good	Bad	Bad	Very good
	Intrusion	Very good	Good	Good	Very good
Tone reversal		Not reversed	Reversed	Reversed	Reversed

- 24nm HP L/S

IC		Low sigma	High sigma A	High sigma B	Dipole
Modulation depth		Bad	Bad	Good	Good
Defect signal	Extrusion	Very good	Good	Not bad	Bad
	Intrusion	Very good	Good	Good	Very good
Detection sensitivity	Extrusion	Very good	Very good	Not good	Bad
	Intrusion	Good	Good	Not good	Good
Tone reversal		Not reversed	Reversed	Reversed	Reversed

Inspectability

	Descriptions
Requirements	• Less than ~10% of total defect counts for HVM
Current Status	• Inspection image of 19X nm inspection tool is not enough to differentiate **false/nuisance** from real defects. • SEM verification is additionally needed. • 30nm HP → 30~50% for worst case but getting better • 22nm HP → not enough data yet (just started) • 16/11nm HP → no data yet
Expected Risks	• Increase of mask noise from mask surface damage due to many cleaning events • Dependency of Pattern/DOI/ illumination condition is increasing • Increase of inspectability-sensitivity tradeoffs
Focus Area	• Enhancement of focus calibration • Study of mask error terms (LER, surface roughness) • Development of more effective filtering algorithm • Optimization of inspection conditions based on blank stack and illumination conditions

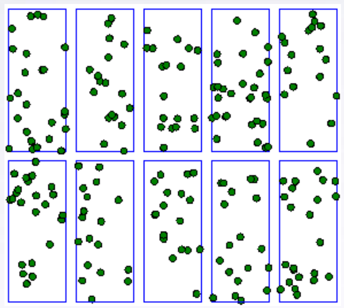
False counts

- 193nm inspection shows many false counts.

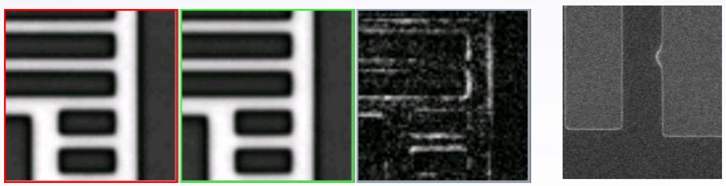
30nm HP

Defect | Ref. | Diff. | SEM

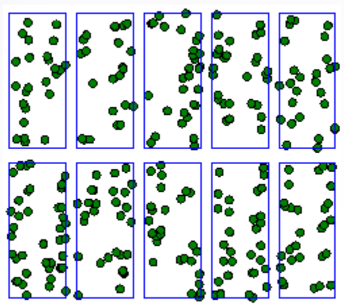
Type A



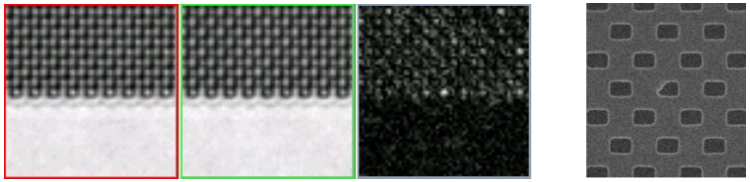
~30% of false



Type B



~40% of false



Throughput time

	Descriptions
Requirements	• 32/22nm HP : ~4hrs per mask • 16/11nm HP : ~6hrs per mask @100X120 mm^2 , HVM
Current Status	• 32/22nm HP with ~50nm pixel shows 3~5 hrs TPT when single inspection is enough • TPT depends on pixel size and computing environment
Expected Risks	• Double inspection due to combination of DOI and illumination conditions (maybe ~ 10 hrs needed) → CoO increase • Increase of false rate → increase of TPT • DB modeling difficulties → increase of computing time
Focus Area	• Study of the necessity of double inspection based on defect type, pattern type and tech. node • DB modeling enhancement • Computing power enhancement to handle image processing • Possibility of new position of e-beam inspection against 19X nm inspection

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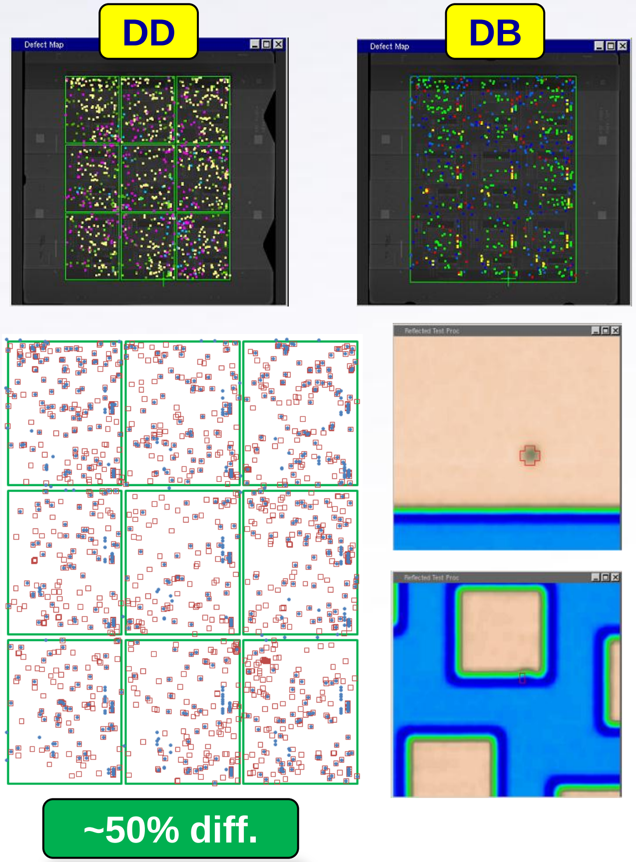
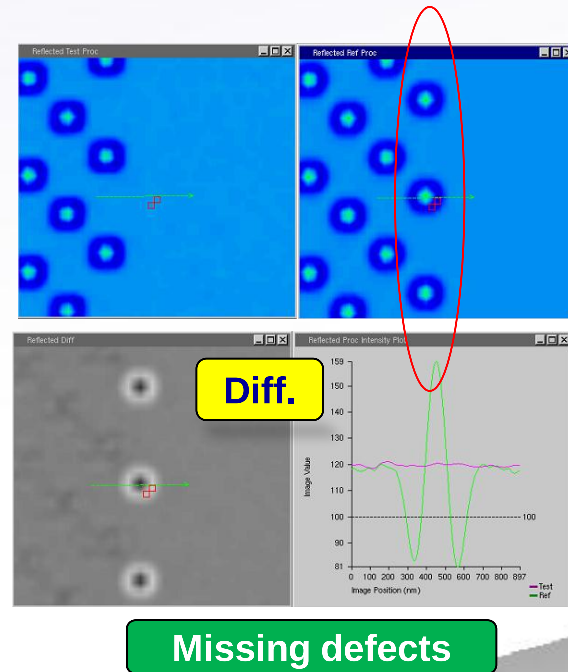
EUV DB Inspection

	Descriptions
Requirements	• Equivalent sensitivity / false rate / TPT with DD inspection
Current Status	• DB inspection of HP32 shows sensitivity differences and some missing defects
Expected Risks	• Sensitivity loss • False counts increase • TPT loss • Repetitive DB modeling might require when new blank is used
Focus Area	• Enhanced EUV DB algorithm • Study of Flare level

EUV DB Inspection

- First try of full EUV mask DB inspection with 30nm HP at 193nm inspector
- Showed sensitivity differences between DD and DB
- Some missing defects observed.





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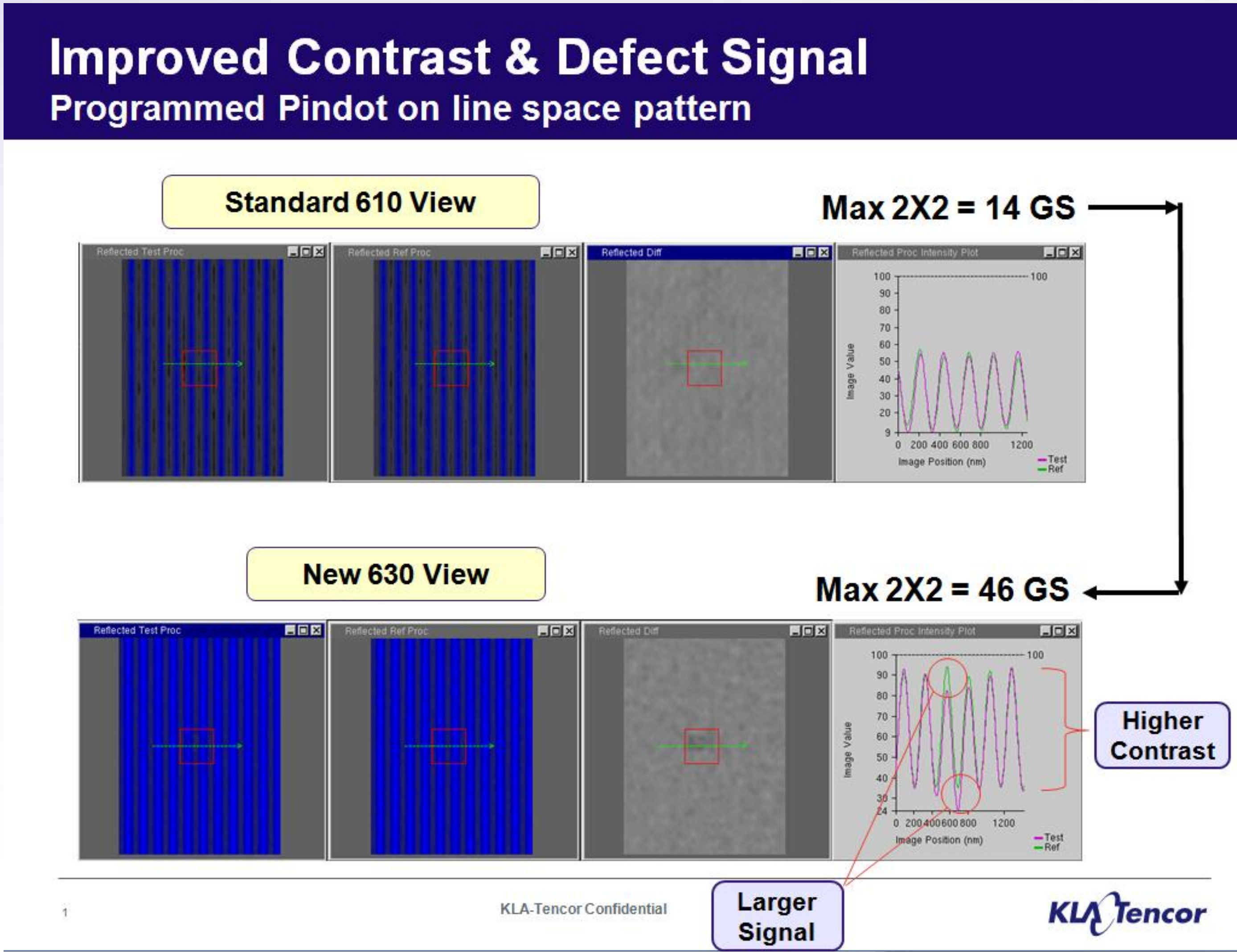
Improvement of EUV DB inspection



Weston Sousa(KT), 2011 BACUS KT RYMS

Defect Review / Classification / Disposition /

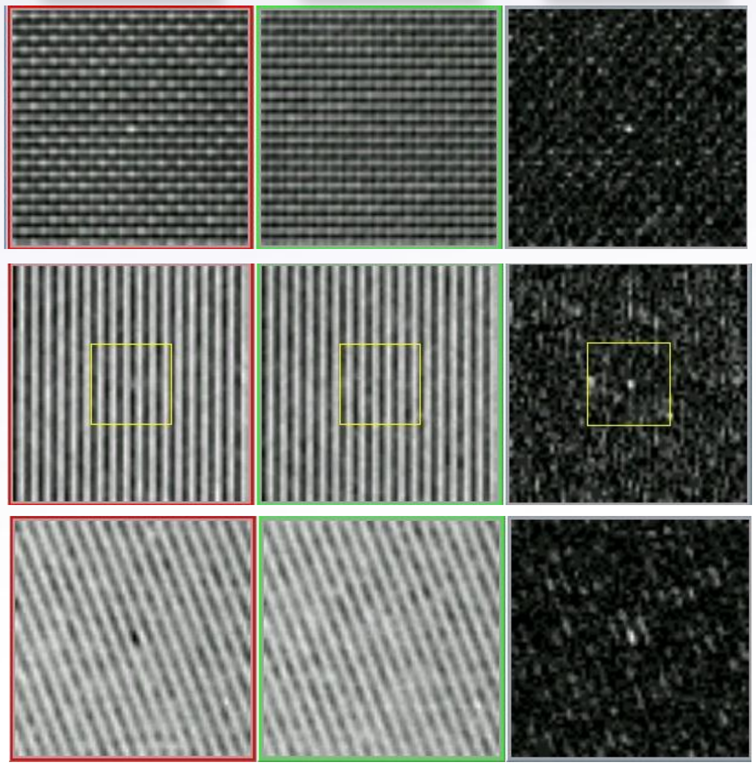
	Descriptions
Requirements	• Good inspection image to judge defect severity
Current Status	• Hard to find defect on inspection image and take time to judge defect disposition to confirm final mask qualification • Need additional SEM review
Expected Risks	• TAT increase due to SEM review of every defects • Wrong judge of mask defect
Focus Area	• Study of simulation capability for defect review and disposition (ex. 3D CD SEM) • Enhancement of inspection optic

Defect Review

- More visibility of defect is needed.

Difficulties of defect review

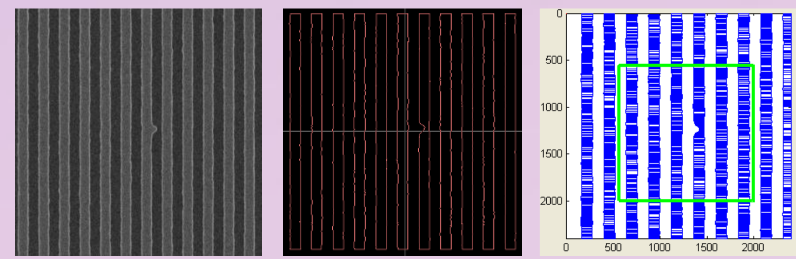
Defect | **Ref.** | **Diff.**



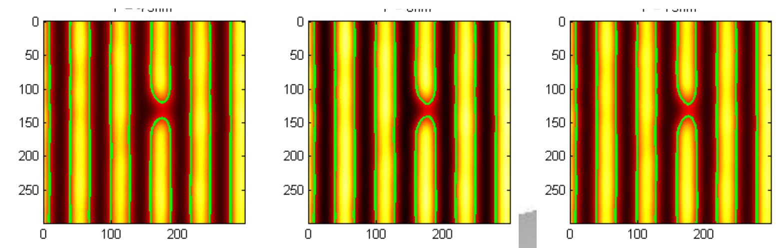
- Predictability of defect is needed.

Defect review using simulation w/ SEM image

Original SEM Image | **Extract Contour GDS** | **Simulate**



Focus=-75nm | **Focus=0nm** | **Focus=75nm**



Vikram Tolani (Luminscent), 2011 BACUS Symposium

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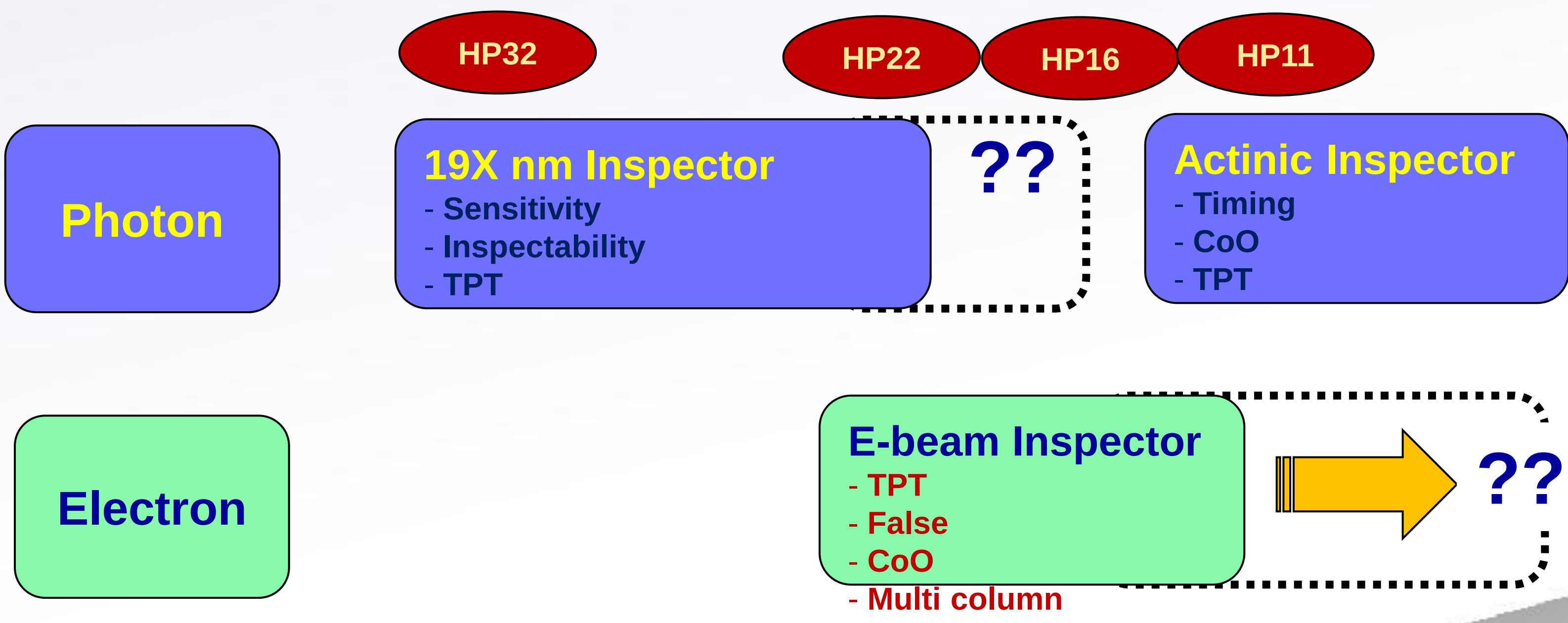
Timing

- Alternatives to close EUV inspection technology gap
  - Extend 19X nm inspector
  - Pull in Actinic inspector
  - Put more efforts in E-beam inspector



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Risk Estimate

	2011	2012	2013	2014	2015	2016	Comments on high, med risk
Sensitivity	med	med	med	high	high	low	- 2014~2015 : 19Xnm limitation
Inspectability	high	high	low	high	high	low	- 2011~2012 : immaturity of 19X nm inspection
Throughput	low	med	med	high	high	med	- Need of double inspection - Smaller pixel with actinic
Contam. Control	low	low	low	high	high	med	- Moving toward HVM for EUVL
Review/ Class. / Disposition	high	high	high	high	med	low	- Lack of visibility of 19X nm inspection tool

- Industry Focus
  - 2011 ~ 2013 : Defect review / classification / disposition / false rate reduction
  - 2014 ~ 2015 : Sensitivity / TPT / Contamination control

Conclusions

- EUV pattern mask inspection will be much more difficult in 3~4 yrs.
- Cost of fab operation of EUV pattern mask inspector will be higher than ever due to lack of sensitivity, increase of false rate which cause loss of Inpsetion TPT.
- Combination of OAI and polarized illumination will give more advantage for EUV pattern mask inspection but it might also give need of double inspection for specific defects of interests.
- Thus, extendibility of 19X nm inspector needs to be clarified.
- In addition, industry also needs to take e-beam inspection into account for bridging or replacing technology for 22nm HP and beyond.
- Risk estimates need to be continuously studied with inspection tool suppliers and EUV mask makers.

Acknowledgements

- My co-author and Samsung's mask team engineers
- Many inspection suppliers for their hard work to close the gap for EUV mask.